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FINAL REPORT
NASA GRANT NAG5-2100
MASS LOSS IN THE INTERACTING SEMI-DETACHED
BINARY DELTA LIBRAE

FOR

GUEST OBSERVER PROGRAM
INTERNATIONAL ULTRAVIOLET EXPLORER

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**MASS LOSS IN THE INTERACTING SEMI-DETACHED
BINARY DELTA LIBRAE**

**The research for this grant has been completed. A paper entitled "IUE
Ultraviolet Spectroscopy of the Interacting Binary Delta Librae" by G. E.
McCluskey, JR., C. P. S. McCluskey and Y. Kondo is being submitted for
publication to The Astrophysical Journal.**

**ULTRAVIOLET SPECTROSCOPY OF THE INTERACTING
BINARY DELTA LIBRAE**

by

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ABSTRACT

The interacting Algol-type binary Delta Librae (A0V + G: V) has been observed with the International Ultraviolet Explorer (IUE) satellite. More than fifty high resolution spectra in the far-ultraviolet and mid-ultraviolet spectrum have been analysed in order to model the mass flow in the Delta Librae system. The resonance lines of Si IV and C IV are present in absorption and vary in strength both secularly and with phase. The radial velocities of the Si IV and C IV absorption lines generally follow the orbital motion of the primary star but deviate by typically a few tens of kilometers per second in the direction of the observer. The presence of Si IV and C IV features indicates the existence of a region considerably hotter than the normal A0V photosphere and since these lines are present at all phases, this region must be fairly extensive. These results are interpreted in terms of a "pseudo-photosphere" around the equatorial region of the A0V star, created by matter being accreted from the G-type companion. The widths of the Si IV and C IV absorption features imply that some of the matter lost by the G-star leaves the system entirely.

1. Introduction

The eclipsing binary Delta Librae = HD 132742 (A0 V + G: V) is a typical Algol-type system with partial eclipses and an orbital period of 2.327 days. The light curve analysis of Koch (1962) and spectroscopic studies of Sahade and Hernandez (1963) and Tomkin (1978) show that the system is semi-detached with the G-star at its critical Roche lobe. The primary star has a mass of 4.9 solar masses and a radius of 4.1 solar radii. The light elements are (Koch 1962):

$$\text{Pr. Min.} = \text{HJD } 2422852.3598 + 2.32725297 \text{ E}$$

Koch (1962) notes anomalies in the light curve indicative of the effects of gas flow. No emission lines have been detected from ground-based observations.

These interactive effects led us to observe Delta Librae with IUE at several times between 1978 and 1985. These spectra show the presence of si IV and C IV absorption features showing both secular and phase dependent variations. In addition, variations indicative of mass flow are seen in the resonance lines of Fe II, Mg II and Al III. It became clear that Delta Librae is undergoing mass flow activity at the present time. Since the system is relatively bright, it was determined that a detailed study of Delta Librae over as small a number of revolutions would be invaluable in separating secular and phase variations and in mapping out mass flow in and out of the system.

2. Observations

With the launch of the IUE satellite, it became possible to study mass flow in the ultraviolet spectral region where it has signatures far more observable than in the optical spectrum. In August 1992, the interacting binary Delta Librae was observed at high resolution for 56 hours with the IUE satellite over a five day period. Approximately 50 spectra were obtained and nearly all are of excellent quality. Phases were calculated using the light elements given in Section 1.

3. Discussion

The most striking features in the spectra of Delta Librae are the Si IV and C IV resonance doublets which are present in absorption at all of the observed phases. In addition, lines of Al II, Al III, C II, Fe II, Fe III, Mg II, Mn II, Ni II, Si II, Si III, Fe II, Fe III and Zn II are present. No detectable emission was present at any phase.

The Si IV doublet shows considerable phase and secular variation. These lines were weaker by about 25% in 1985 than in 1978 or 1992. They were of comparable average strength in 1978 and 1992. The equivalent widths of these lines were about 50% stronger at phases 0.70 to 0.90 than at other phases except that near phase 0.25 they were weaker than at any other phase.

This is a common phenomenon in interacting Algol-type binaries. The radial velocities of the Si IV components show a general bias of -40 to -60 kms^{-1} . However, near phase 0.75 the velocity is near -100 kms^{-1} . The C IV and Al III behave in a similar fashion. In the mid-ultraviolet, the Fe II and Mg II resonance lines show an analogous but smaller effect. Other than eclipse effects, no significant continuum variations were found in the ultraviolet spectrum of Delta Librae.

It is clear that significant mass flow is occurring in Delta Librae. It is relatively widespread with a concentration of material visible between phases 0.70 and 0.10. The C IV lines seem to form at a greater distance from the A0V star than the Si IV lines. The broad nature of the excess absorption in the Si IV and C IV lines shows that narrow gas streams are not major contributors but that a more diffuse flow is present. At phases 0.00 to 0.60 gas which has circled around the A-star and is approaching the observer is detected. At phases 0.60 to 1.00, gas falling onto the A-star is observed. This accounts for the increase in strength of the lines after secondary eclipse since only part of the gas will succeed in circling the primary star and cause the absorption after primary eclipse. The extreme velocities strongly imply that some material is escaping from the system. The Si IV and Al III lines, minus any photospheric contribution, are formed relatively close to the surface of the primary star and are part of the diffuse flow surrounding the equatorial regions of this star but more concentrated on its following hemisphere. This "pseudophotosphere" is created and energized by the interaction of the gas falling from the cool companion onto the A-star. Since the continuum of the A-star is unaffected by this pseudophotospheric material, the optical depth of this material must be very small in the continuum. These effects are quite similar to those reported for U Sagittae, TX Ursae Majoris and a number of other interacting Algol-type systems.

4. Conclusions

The interacting binary Delta Librae is currently in a state of moderate mass flow. It appears to be slightly more active than U Sagittae and less active than U Cephei. Except for the difference in the strength of the flow, it is quite similar to U Sagittae and U Cephei (in its normal state). It is very important to obtain more accurate information about the secondary component, particularly its effective temperature. Infrared measurements during the partial eclipse of the primary star should help to answer these questions. Despite its relative brightness, Delta Librae has been generally neglected by ground-based observers, probably because its eclipses are partial. However, it is a very important system in that a better knowledge of its properties will give us more clues to the problems of mass flow and evolution of the Algol-type binaries.

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Table 1

IUE Radial Velocities of Delta Librae

Phase	Vr*,pr	Si IV**	C IV**	Fe II(2599)	II**
0.25	-70	-99	-117	-115	-65
0.61	+44	+28	0	- 5	+58
0.78***	+68	+19	+ 42	+ 1	+63

*Assuming $K_1 = 77 \text{ kms}^{-1}$

**Mean of individual doublet values.

***Mean of two spectra.

Table 2

Absorption Line Equivalent Widths

Ion	P H A S E		
	0.25	0.61	0.78
Si IV (1393)	0.53	0.96	1.15
Si IV (1402)	0.24	0.80	0.90
Si II (1526)	0.72	1.11	1.08
Si II (1533)	1.09	1.11	1.10
C IV (1548)	0.30	0.77	0.80
C IV (1550)	0.31	0.62	0.77
Al III (1862)	0.42	0.86	1.01
Fe II (2359)	0.80	0.86	0.91
Fe II (2411)	0.48	0.50	1.00
Fe II (2599)	0.67	0.90	1.09
Mg II (2795)	1.11	1.84	2.26
Mg II (2802)	0.67	0.83	0.78

HD 132742 = DELTA LIB
L6471 AND L6472
Mg II
CENTER AT 2802, 10 Å WIDE

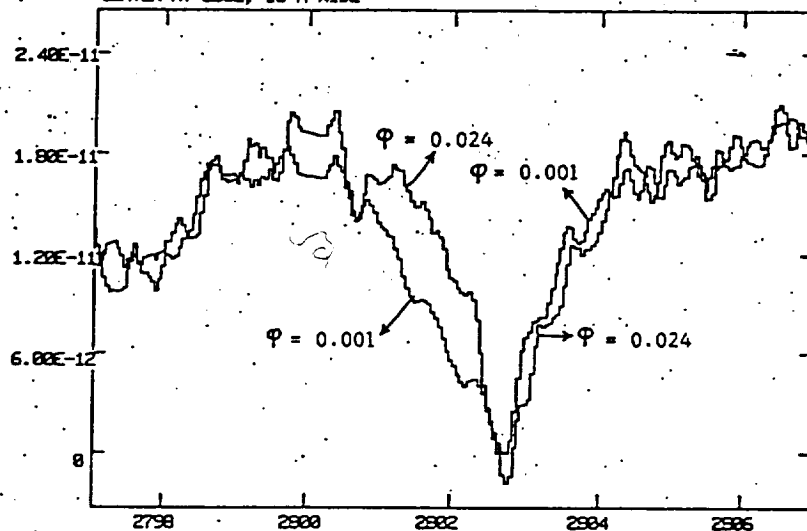


Fig. 1 Rapid variations (80 minutes) in the $\lambda 2802$ Mg II line of Delta Librae from phase 0.001 to 0.024. Excess shortward absorption is present at phase 0.001.

HD 132742 = DELTA LIB
L6470, L7887, L9699
CENTER = 2599
Fe II

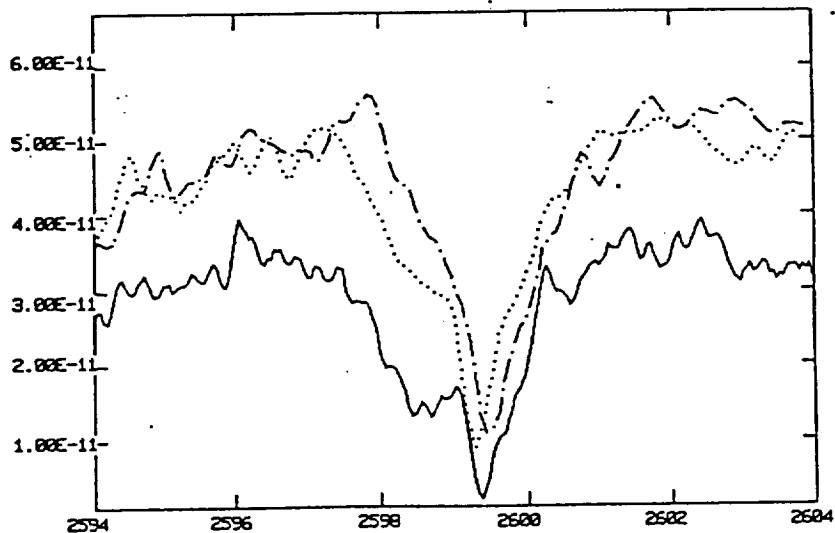


Fig. 2 Variations in the $\lambda 2599$ Fe II line of Delta Librae. Dash-dot curve is phase 0.738 in 1981; dotted curve is phase 0.855 in 1980; and solid curve is phase 0.974 in 1985 (hot star partially eclipsed).